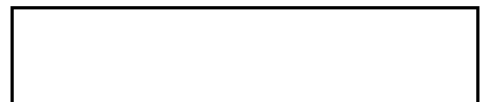


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ENGINEERING REPORT NO. 8976

PSYCHOPHYSICAL GEMS STUDY

FINAL REPORT

DATE: October 16, 1967

PREPARED FOR: SPO 27203

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<u>Section</u>	<u>Title</u>	<u>Page</u>
	ABSTRACT	ii
I	PSYCHOPHYSICAL STUDY INTRODUCTION	1
	1.1 General	1
	1.2 Parameters of GEMS	1
	1.3 GEMS Viewing Factor	2
II	DISCUSSION OF GEMS STUDY RESULTS	3
	2.1 Statement of Study Objectives	3
	2.2 Results of Experiment I	4
	2.3 Results of Experiment II	5
	2.4 Results of Experiment III	8
	2.5 Realism of Simulations	10
III	STUDY CONCLUSIONS	11
	3.1 Study Implications	11
	3.2 GEMS - An Evaluation Tool	12
	APPENDIX A - Psychophysical GEMS Study Report	
	APPENDIX B - Psychophysical GEMS Matrix Data	
	Report	

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ABSTRACT

A psychophysical study was conducted to determine the usefulness of GEMS as a subjective image quality evaluation tool. The study results definitely established the fact that GEMS can be employed to obtain realistic estimates of system performance. The study experiments provided valuable information concerning the matrix increment spacings for modulation transfer function and ground exposure. The data also indicates that the GEMS parameters are unique.

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SECTION I

PSYCHOPHYSICAL STUDY INTRODUCTION

1.1 GENERAL

A program task of utmost importance is the Psychophysical GEMS study. The prime objective of the study is to determine the usefulness of GEMS as a means of subjectively evaluating mission material. A study was performed with three GEMS matrices at the customer's facility by [REDACTED]

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[REDACTED] The experiments conducted by [REDACTED] were designed to gain an insight on (1) how fine an increment spacing of modulation transfer function (MTF) and ground exposure could be distinguished by photo-interpreters, (2) the uniqueness of each parameter, (3) the accuracy and repeatability of judgments, and (4) the ability of interpreters to rank mission material with GEMS.

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[REDACTED] study report is included in this report as Appendix A. The study results have been reviewed by [REDACTED] and an interpretation of these results is discussed in the following sections of this report. Before proceeding with a discussion of the tests and the results, a basic understanding of the stimuli material is essential.

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1.2 PARAMETERS OF GEMS

Matrix arrays of MTF and exposure were generated for three different type scenes. The parameters of these matrices were defined in conjunction with the customer and also based on the findings of the System Parameters study. The ten levels of simulated MTF were inclusive of a 6.3 to 16.2 foot ground resolution range at 10% increments of resolution. It was the intent of the study to determine the increment spacing for MTF above and below the present best performance level of the system.

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The seven increments of ground exposure were simulated to represent a total exposure shift of 0.38 density units. This simulated exposure range corresponds to approximately a ± 0.20 density shift on either side of the average ground exposure value determined in the System Parameters study. The increment spacing was varied from 0.02 to 0.15 density units. The exact values of each increment can be obtained from Appendix B, the Psychophysical GEMS Matrix data report.

The scene content of the GEMS consisted of a harbor, an airfield, and a city area. The scale of the imagery was a fixed parameter for the experiment.

1.3 GEMS VIEWING FACTOR

Due to the problems of controlling MTF above 100 cycles per millimeter in the simulation process and obtaining original material with the proper photographic parameters, the psychophysical GEMS were generated at three times the scene scale of the appropriate mission material. The desired scene scale factor was simulated by viewing the mission material at three times the viewing magnification of the GEMS. To account for any apparent differences in image grain size, the GEMS were simulated on a film type that visually appeared to yield the same grain structure as type 3404 film at a factor of three less viewing magnification. The spatial frequency extent of the simulated MTFs also were generated to account for this difference in viewing magnification.

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SECTION II

DISCUSSION OF GEMS STUDY RESULTS

2.1 STATEMENT OF STUDY OBJECTIVES

The psychophysical tests were divided into three experiments. The first experiment involved only the use of GEMS. Experiment I was concerned with psychologically scaling the parameter of MTF. The purpose of the experiment was to obtain the necessary information required to specify the equal visual increment spacing for this parameter.

Experiment II was designed to determine the psychological scaling of the ground exposure parameter and to test how accurately and reliably subjects could judge the parameters of MTF and exposure. The tests also were designed to determine if the parameters of the matrix array were unique. In other words, that there were no two elements of a matrix array that produced the same equivalent impression of MTF and exposure.

Experiment III was conducted to determine how reliably subjects could judge the MTF and exposure levels of mission material with GEMS. The accuracy of these judgments could not be determined since no objective measurements were made of the imagery used in the tests.

The details pertaining to methods and procedures of each experiment have been thoroughly covered in the [] report. The text of the [] report will be confined to a discussion and an interpretation of the study results with a few minor exceptions.

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2.2 RESULTS OF EXPERIMENT I

2.2.1 MTF Spacing

The results of Experiment I indicate that equal visual increments changes of MTF are obtained when the MTF parameter is equally spaced logarithmically. The experiment also indicated that a 67% discrimination of MTF is obtainable with an increment spacing corresponding to 1.4 log steps. A 1.4 log step is equivalent to a 14% change in ground resolution.

2.2.2 Definition of Resolution Terms

To avoid any misunderstanding between the use of the terms MTF and ground resolution, it will be necessary to define the meaning of these terms in relationship to how they apply to the study. MTF spatial frequency is a parameter which is dependent upon the viewing magnification factor. Thus, when an observer views 50 lines per millimeter imagery with a 10 power microscope, the spatial frequency extent of the imagery observed by the eye is only 5 lines per millimeter. In simplified terms, this means that the film imagery MTF is just translated from a 50 to a 5 line per millimeter extent. Visually, the spread function size of the imagery is just enlarged by the magnification factor of the optics, provided the optics of the microscope do not introduce additional degradations.

However, when speaking of the ground resolution (in feet) of the imagery, the ground resolution value remains the same regardless of the viewing magnification factor and provided no degradations are introduced by the optics. Since the simulation of MTF was made to be dependent upon viewing magnification, it was perceived that it would be best to express the MTF results in terms of ground resolution to avoid any confusion that might result due to the use of the various magnification factors. When the 10% increment values

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were established for the GEMS matrix MTF spacing, the increments were expressed in terms of limiting spatial frequency resolutions. These limiting resolution values (in lines per millimeter) can be directly converted into ground resolution values (feet) with the use of the imagery scale factor. Therefore, when discussing a 14% change in ground resolution, the equivalent change in limiting spatial frequency resolution is also 14%.

The increment spacing of MTF was based on the limiting resolution values to avoid the ambiguity of specifying percentage changes in MTF curve position at some arbitrary modulation level.

2.3 RESULTS OF EXPERIMENT II

2.3.1 MTF and Exposure Scaling

The findings of Experiment II verified that the MTF increments of GEMS should be established at equal logarithmic steps. To obtain 67% discrimination, the MTF steps should correspond to 12.5% increments of ground resolution. It may be recalled that the results of Experiment I indicated 14% increments. Since the population of subjects is greater for Experiment II, it seems reasonable to accept the 12.5% number as a measure of the MTF increment spacing.

Experiment II also implies that 67% discrimination of exposure shift is obtained with an increment spacing of 0.06 density units.

2.3.2 Uniqueness of Parameters

One objective of the Psychophysical GEMS study was to determine that the elements of the GEMS matrix were unique. In order to obtain a valid estimate of system performance with a GEMS matrix array, it is important that no two elements in an array will be judged as being equivalent in MTF and

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considered surprisingly low, and it exhibits the measurement accuracy and simulation control for the entire GEMS simulation process. As much as a $\pm 15\%$ variation in MTF existed among the original three scenes, and the variation over the format of any one scene was just as great. An attempt was made to minimize the MTF variations of the original scenes when generating the master transparencies. If one takes into account that additional errors are introduced by two independent MTF evaluation steps for each scene and that there is a $\pm 1\%$ variability in the MTF simulation process among scenes, a total ground resolution simulation variability error of $\pm 6\%$ could realistically exist.

The tests indicate that the exposure level of Scene A, the harbor area, was approximately 0.11 density units denser than Scene C. An explanation for this discrepancy can be given. The average density value for each GEMS scene at a common exposure level was established to be the same when evaluated. In the case of the harbor scene, the average density value was obtained from density readings of both the image structure and the water. Since the water is represented in the GEMS by low densities, it follows that the image

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structure of the harbor scene must be higher in density in order to achieve an average scene density equivalent to that obtained from a transparency that only consisted of image structure.

Actually, the average densities for the three scenes should have been determined from imagery common to all scenes. During the tests, the subjects matched the exposure levels by examining areas in the scenes with common imagery and not by obtaining an integrated effect of the whole scene. When considering that the resolution of the imagery is exposure dependent, the procedure employed by the subjects to match exposure is most valid. Re-evaluation of only the image structure areas of Scenes A and C verified the fact that the average image structure density of Scene A was greater than Scene C. The re-evaluation established the average density of Scene A to be denser by 0.14 density units. The reported value of 0.11 density units is in agreement.

2.3.4 Parameter Increment Spacing

To summarize, the findings of the study indicate that a 67% discrimination of MTF and exposure can be obtained if the MTF increments are 12.5% ground resolution differences and the exposure increments are 0.06 density unit differences. The discrimination level of each parameter is not the only criterion to be examined in establishing increment spacing. The discrimination levels sometimes can be too coarse or too fine to serve as an efficient and/or effective evaluation tool.

It is believed that the exposure increments, if established at 0.06 density differences, would be too fine an increment spacing. The test results imply that, for the 0.38 density exposure range simulated, little or no change in resolution was observed due to the total exposure shift. This test result was substantiated by visual examination of a medium contrast AFBT which was employed in the GEMS' control and evaluation target array. Inspection

of the AFBT at both ends of the exposure range indicated that the resolution did not change by a full AFBT element. Simultaneous viewing of the same two AFBT elements, at each end of the exposure series, only yielded the impression that the over-exposed element was slightly more resolvable than the under-exposed element.

If a matrix array with an exposure parameter is to serve as a useful evaluation tool, the increment spacing of exposure should be established on the basis of the degree of exposure shift that produces a 12.5% change in limiting ground resolution. When specifying an exposure increment corresponding to a 12.5% difference in ground resolution, it should be noted that this increment spacing is not acquired by introducing a shift in the MTF; but that it solely results from changes in the contrast of the imagery and the film granularity at the various exposure levels. Since the change in limiting ground resolution is not a linear function of exposure, the density increment shifts of exposure will not be equally spaced. For the camera system and film type involved, 4 to 6 exposure levels would be required for the GEMS matrix.

It also is suggested that the MTF parameter be established at a 12.5% ground resolution increment spacing. For measures of mission material quality, as fine an increment spacing that can be visually detected, is desirable. When making comparisons with the use of a split field microscope, it is possible that the MTF discrimination level at this increment spacing could be greater than 67%.

2.4 RESULTS OF EXPERIMENT III

A GEMS matrix array was employed with a number of mission material scenes to determine how well different subjects agreed on their judgments of the MTF and exposure levels of the mission photographs. Standard deviations

were computed from the subjects' responses for each mission scene. The mean of the standard deviations for the MTF levels of the mission photographs was computed to be 19% as opposed to a standard deviation of 12.5% when matching one GEMS against another in Experiment II. The difference between the two standard deviation values was not statistically significant.

The computed increase in the MTF standard deviation may be related to the general comments stated by the subjects during the Experiment III test. When matching a photograph with a GEMS, some subjects found a match in limiting resolution detail, but observed that the edge sharpness between the two photographs did not quite agree. This comment signifies that the shapes of the two photographic image spread functions, as observed by the eye, were not identical. If this condition prevailed and some subjects based their judgments on limiting resolution and others based their judgments on edge sharpness, it would be anticipated that the mean standard deviation value would increase. The observed difference between limiting resolution and edge sharpness is either associated with the simulated MTF curve shape and/or with the differences in the MTF of the two viewer optical systems.

The mean of the standard deviations for the exposure levels of the mission photographs was 0.065 density units. The standard deviation of exposure with the GEMS was computed to be 0.06 density units. Results of this nature represent excellent agreement.

It can be concluded that the agreement among subjects as to their judgments of the MTF and exposure levels of the mission photographs was approximately as good as with the GEMS. Nothing can be stated about the accuracy of their judgments since no objective measures exist for the mission material imagery used in the study.

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2.5 REALISM OF SIMULATIONS

Outside of the comment discussed in Paragraph 2.4 about the observed differences in limiting ground resolution and edge sharpness, the subjects thought that the simulations were quite realistic of the appearance of mission material.

The subjects suggested that the scale of the buildings did not seem to match the mission material even though the cars and streets looked identical in size. It is believed that the noted difference in building scale size was the result of observing the imagery with two different microscope fields of view. Since the GEMS were viewed at a 20 times magnification, the field of view was such that a few entire buildings were observed by the eye: where, at

SECTION III

STUDY CONCLUSIONS

3.1 STUDY IMPLICATIONS

3.1.1 Parameter Scaling

The study results indicate that equal, visually discriminable steps of MTF and exposure are obtained for the ranges of the parameters tested if the increments of ground resolution are spaced at equal logarithmic steps and the increments of exposure shift are spaced at equal density steps. A 67% accuracy of discrimination is obtained for both parameters if the MTF steps are established at 12.5% resolution intervals and the exposure steps are established at 0.06 density intervals.

The results imply that an exposure shift interval of 0.06 density units is too fine for image quality evaluation purposes since no changes in resolution due to exposure are discernable for the entire simulated exposure range of the study GEMS. For the GEM matrix array, it is suggested that the exposure increments be established to correspond to exposure shifts that produce 12.5% changes in limiting ground resolution.

An MTF interval of 12.5% ground resolution is as fine an increment spacing as can be discriminated with reasonable accuracy. It is suggested that this MTF interval be established as the increment spacing for the GEMS matrix array. With the use of a split field viewer for making comparisons, the accuracy of MTF discrimination may be improved.

3.1.2 Other Study Findings

The experiment concerning the ranking of mission material with a GEMS matrix indicated that the subjects' judgements of the MTF and

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exposure levels of the mission photographs were just as reliable as their judgments when ranking one GEMS against another. In other words, the mean standard deviations of their judgments for each parameter were statistically the same in both experiments. The accuracy of their judgments could not be determined since no objective measures were made of the mission photographs used in the study.

A very interesting and important finding of the study was that scene content seemed to have no effect on the subjects' judgments of MTF or exposure. This finding strongly suggests that the parameter of scene content can be confined to few scenes of various type imagery.

3.2 GEMS - AN EVALUATION TOOL

All indications of the Psychophysical GEMS study point to the fact that GEMS can be employed in the evaluation of mission material. The results of the study show that photo-interpreters can distinguish and rank independently the parameters of exposure and MTF. Their ability to discriminate levels of exposure is better than is necessary. Although their discrimination of MTF levels may be slightly less sensitive than desired, reasonable estimates of MTF levels are obtainable with GEMS.

The major attributes of GEMS are that they can supply estimates of system performance quite rapidly and that these estimates are not dependent upon either specific type targets or complicated instrumentation that requires lengthy operator training time. It probably would require a minimum of 4 to 8 hours to objectively evaluate, without an on-line computer to the instrumentation, the parameters of a single scene area that could be estimated with a GEMS matrix in a matter of a few minutes.

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A point worthy of serious consideration is that the GEMS estimates of MTF are almost as accurate as the MTF objective determination of mission material, because of the variable factors associated with the typical targets used in the measurement process. Under certain conditions, where the quality of imagery is varying over the format and no objective measurement targets exist in the areas of interest, the MTF estimates obtained with GEMS can be much more accurate than any inferred evaluations. Image quality variations occur quite frequently due to variable haze conditions or variable cloud coverage exposure conditions.

In summary, the psychophysical study demonstrated that GEMS can provide a useful service as a rapid evaluation tool.

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APPENDIX A

Psychophysical GEMS Study Report

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THE JUDGMENT OF GROUND RESOLUTION
AND EXPOSURE SHIFT OF AERIAL PHOTOGRAPHS

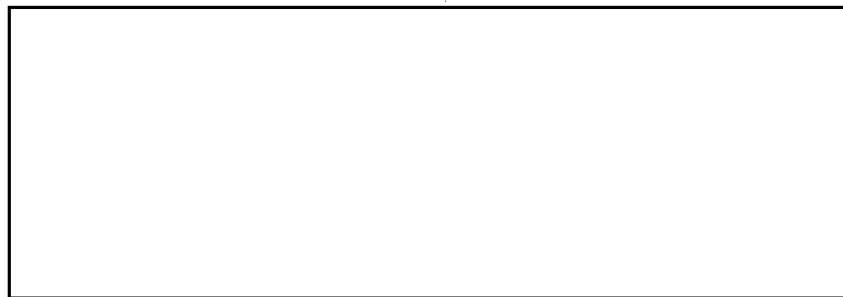
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ACKNOWLEDGMENTS

The assistance given by is very much appreciated. He, with the aid of T__ personnel, supervised the experimental sessions. The author wishes also to thank the staff members of T__, who patiently spent hours of their time serving as subjects.

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TABLE OF CONTENTS

	Page
ACKNOWLEDGMENTS	ii
LIST OF TABLES AND FIGURES	iv
STUDY OBJECTIVES	1
EXPERIMENT I	2
<i>Purpose</i>	2
<i>Method</i>	2
<i>GEMS</i>	2
<i>Subjects and procedure</i>	2
<i>Results and Discussion</i>	4
EXPERIMENT II.	7
<i>Purpose</i>	7
<i>Method</i>	7
<i>GEMS</i>	7
<i>Experimental design</i>	9
<i>Subjects and procedure</i>	9
<i>Results and Discussion</i>	9
<i>Scaling</i>	9
<i>Accuracy of judgment</i>	13
<i>Reliability of judgment</i>	20
EXPERIMENT III	23
<i>Purpose</i>	23
<i>Method</i>	23
<i>Photographs</i>	23
<i>Subjects and procedure</i>	23
<i>Results and Discussion</i>	23
IMPLICATIONS	25

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LIST OF TABLES AND FIGURES

Table		Page
1	THE GROUND RESOLUTION AND EXPOSURE SHIFT OF THE GEMS.	3
2	EXPERIMENTAL DESIGN	10
3	ANALYSIS OF VARIANCE OF ERRORS OF EXPOSURE-SHIFT JUDGMENTS	14
4	ANALYSIS OF VARIANCE OF ERRORS OF GROUND-RESOLUTION JUDGMENTS.	17
5	MEANS OF THE STANDARD DEVIATIONS.	22
6	MEANS AND STANDARD DEVIATIONS OF MISSION AND PHOTOGRAPH JUDGMENTS.	24

Figure

1	Proportion of judgments of "better resolution" as a function of ground resolution.	5
2	The relation between ground resolution and judgments in Z units. All three series from Figure 1 combined	8
3	The relation between ground resolution and visual scale values	11
4	The relation between exposure-shift and visual scale values	12
5	Mean error of exposure-shift judgments as a function of exposure shift and scenes	12
6	Mean error of exposure-shift judgments as a function of ground resolution and scenes.	16
7	Mean error of ground-resolution judgments as a function of resolution and scenes	18
8	Mean error of ground-resolution judgments as a function of exposure shift and scenes	20

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STUDY OBJECTIVES

The goal of this study was to determine how well humans can judge the quality of aerial photographs by having them compare one set of photographs with a standard set. Although there is a large number of determinants of photographic quality, this study was concerned with only two of them--ground resolution and exposure shift.

To achieve this goal, aerial photographs were produced with ground-resolution and exposure-shift values. These photographs (hereafter referred to as GEMS) and mission (operational) photographs were used in a series of three experiments to achieve the following objectives:

1. To scale psychologically exposure shift and ground resolution. The purpose of this scaling was to determine the relation between physical measures of exposure shift and ground resolution on the one hand, and psychological values on the other. Psychological scaling provides the information necessary to space the GEMS at equal visual increments.
2. To determine how accurately and reliably trained subjects can judge the exposure shift and ground resolution of photographs.
3. To determine whether or not the judgment of ground resolution and exposure shift is visually independent. That is, to determine whether the exposure-shift value of a photograph affects the accuracy of ground-resolution judgments, and to determine whether ground resolution of a photograph affects exposure-shift judgments.
4. To determine how reliably subjects can judge the exposure shift and ground resolution of mission (operational) photographs. Accuracy of judgment could not be assessed because no exact specifications of ground resolution and exposure shift were available for the aerial photographs.

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EXPERIMENT I

Purpose

The primary purpose of Experiment I was to determine whether the difference among the ground resolutions of the GEMS were sufficiently discriminable to be used in Experiments II and III. The secondary purposes of Experiment I were to psychologically scale ground resolution and to establish a "just noticeable difference" for ground resolution, that is, a reliably discriminated difference in ground resolution.

Method

GEMS. Two sets of GEMS were used in this experiment, a set of a harbor scene (Scene A) and a set of an airfield (Scene B). All of the GEMS were negative transparencies. Table I (Page 3) shows the exposure shift and ground resolution of the 70 Scene-B GEMS and 21 Scene-A GEMS. Each cell in the table represents one Scene-B GEM with a particular combination of ground resolution and exposure shift. (The cells marked with Xs refer to the GEMS used in Experiment II.)

Each Scene-A GEM was a combination of one of the seven exposure-shift values with one of three ground resolutions--13.1, 10.7, and 7.8 feet. The density value of .00 refers to an underexposed (light) GEM, and the density value of .38 refers to an overexposed (dark) GEM.

Subjects and procedures. The six subjects who participated in this study were experienced in viewing aerial photographs. Their experience ranged between one and ten years with a median of 3.5 years. Each of the 21 GEMS from Scene A served as a standard for judging a series of five GEMS from Scene B. The selection of the Scene-A GEMS to serve as standards was arbitrary. In each series, one of the GEMS was equal, two were worse, and the other two were better than the ground resolution of the Scene-A GEM. For example, one of the standards from Scene A had a resolution of 13.1 feet at a density of .00; the resolutions of the Scene-B GEMS were 16.2, 14.6, 13.1, 11.8, and 10.7 feet. Each subject, then, made a total of 105 judgments, five judgments for each of 21 series.

The Scene-B and Scene-A GEMS were assigned a random number. Each subject was given a response sheet with the order in which he was to judge the GEMS. His task was to select the standard from Scene A and the comparison GEM

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TABLE 1
THE GROUND RESOLUTION AND EXPOSURE SHIFT OF THE GEMS

		GROUND RESOLUTION (FEET)									
		16.2	14.6	13.1	11.8	10.7	9.6	8.6	7.8	7.0	6.3
EXPOSURE SHIFT (DENSITY UNITS)	.00										
	.02			X		X		X		X	
	.05			X		X		X		X	
	.08			X		X		X		X	
	.13			X		X		X		X	
	.23			X		X		X		X	
	.38										

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from Scene B, and place each on the two stages of a High-Power Stereo-Viewer. Viewing one GEM through one ocular of the microscope, and the other GEM through the other ocular, he alternated between two eyes. The subject judged whether the Scene-B GEM was better or worse in resolution than the Scene-A GEM. If he judged the Scene-B GEM better, he circled the number of the GEM on his response sheet. If its resolution was worse than the Scene-A GEM, he did not circle the number.

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The order of the GEMS in a series, the three series at each density level, and the seven sets of three series (one set at each density), was randomized separately for each subject.

Each subject worked at his own rate, and rested whenever he felt tired.

Results and Discussion

Preliminary analyses showed the exposure shift of the GEM had no effect on the judgment of resolution. Therefore, the judgments were pooled over levels of exposure shift. The pooling resulted in three series with standards of 13.1, 10.7, and 7.8-foot ground resolution.

Figure 1 (Page 5) shows the proportion of "better resolution" as a function of ground resolution for each of the three series. The results showed that discrimination (indicated by the slope of the function) was about equal for the three series. This result means that a logarithmic spacing of ground resolutions leads to equally discriminable steps throughout the series, at least when the ground resolution ranges from 16.2 to 6.3 feet as it did in this experiment.

Inspection of the three series shows a peculiar result. In all three series, the Scene-B GEM that was supposedly equal in ground resolution to the standard was judged to be better than the standard Scene-A GEM. The proportion of judgments "better resolution" for that Scene-B GEM in Series 1 through 3 was approximately .57, .71, and .71. If the two GEMS were judged to be equal, the proportion should have been close to .50 for each of the series.

To determine if the discrepancy between the expected proportion of .50 and the observed proportions was a reliable one, the proportion of judgments "better resolution" were combined for the three Scene-B GEMS, the GEMS which supposedly were equal in ground resolution to the Scene-A GEMS. The mean of the judgments of "better resolution" was .66. A critical ratio showed that there was a statistically significant difference between the mean proportion

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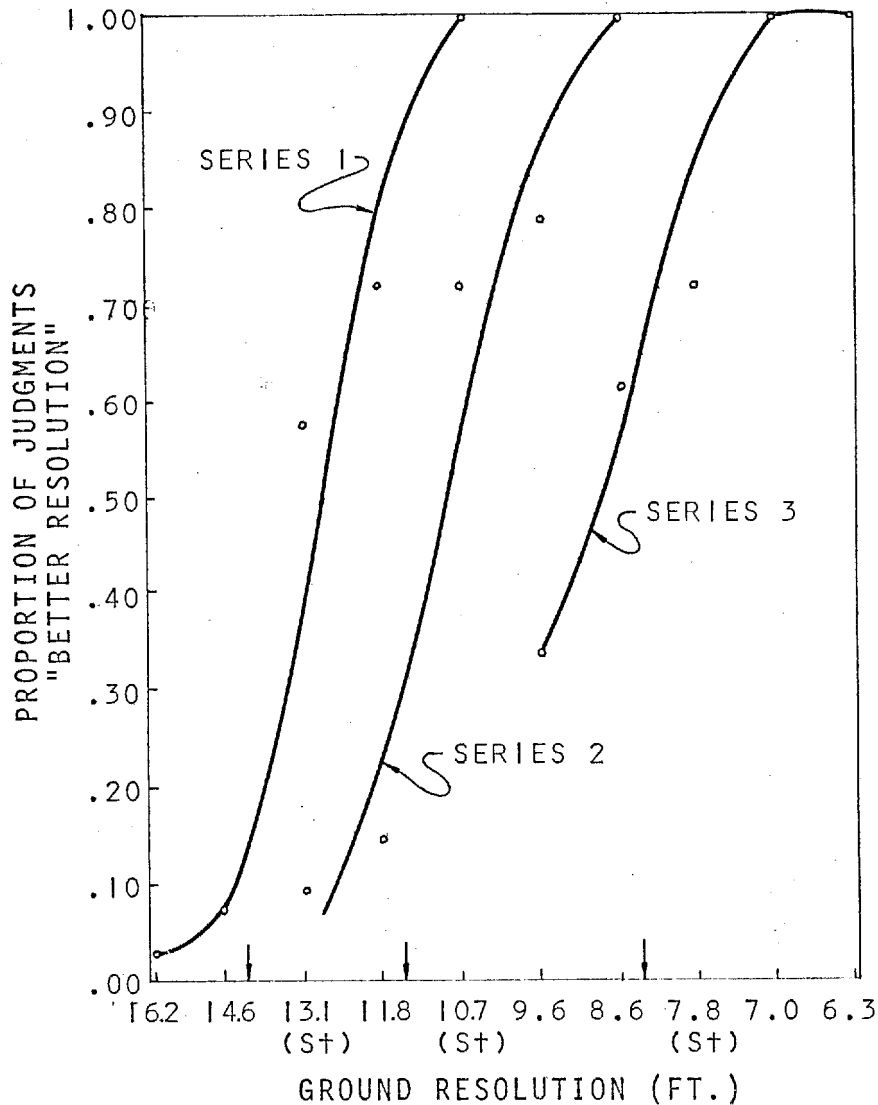


Fig. 1. Proportion of judgments of "better resolution" as a function of ground resolution (St = standard Scene-A GEM; ↓ indicates adjusted standards).

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of .66 and the expected proportion of .50 ($CR = 12.53$, $p < .01$). This finding implies that the ground resolution of the Scene-B GEMS may have been better than that of the Scene-A GEMS. Additional evidence for this conclusion will be presented in Experiment II.

Another peculiarity of the results shown in Figure 1 was the increase in the proportion of judgments of "better resolution," from Series 1 to 3. If, as the mean proportions indicated, the standards were actually worse than the ground resolutions specified on the abscissa in Figure 1, the results do seem reasonable and may be accounted for in the following way: Assume the ground resolutions of the standards in the three series were actually those values (adjusted standards) indicated by the arrows on the abscissa in Figure 1. (The values for the adjusted standards were obtained from the results of Experiment II.) By assuming this, the results shown in the figure may be due to the commonly observed "central tendency" effect in psychophysics. (The central tendency effect manifests itself as an underestimation of stimulus values at one end of a continuum and overestimation at the other end.) In Series 1 and 2, the adjusted standards were overestimated: The point of subject equality¹ was slightly better than 13 feet in Series 1 (overestimated by 1.5 feet), and 10.7 feet in Series 2 (overestimated by less than one foot). Put in another way, in relation to the adjusted standard, the ground resolutions of the Scene-B GEMS were underestimated and the underestimation was larger for Series 1 than it was for Series 2. In Series 3, the adjusted standard was underestimated; the point of subject equality was 8.6 feet (underestimated less than .5 feet). In contrast, then, the ground resolution of the Scene-B GEMS in Series 3 were overestimated in relation to the adjusted standard. This progressive change from underestimation of the ground resolution of the Scene-B GEMS in Series 1 to an overestimation of those in Series 3 resulted in an increase in the proportion of "better resolution" judgments from Series 1 to 3.

The above explanation, though speculative, is certainly reasonable. If the explanation is not acceptable, the only other obvious explanation of the result is that as the ground resolution improved there was a systematic increase in the difference between the ground resolution of the Scene-A and Scene-B GEMS.

To determine the relation between ground resolution and discrimination, the judgments of the three series were

¹The point of subjective equality is the value on the abscissa judged to be equal to the standard; i.e., the value that elicits a proportion of .50.

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pooled. The proportion of judgments of "better resolution" were combined and transformed to Z units (equal Z units are assumed to be psychologically equal). Figure 2 (Page 8) shows the relation between Z units and ground resolution. (There is no data point in Figure 2 for the best resolution because the proportion for this resolution was 1.0 and the Z value for 1.0 is infinite.) Figure 2 showed the relation between ground resolution and psychologically equal intervals is linear. This means that equal steps in log ground resolution produced equal visual changes.

The figure also showed that a change of 1.4 log steps in ground resolution was equal to one Z unit (the value of 1.4 is equal to one-half the range of minus one Z to plus one Z value on the abscissa). A one Z value of 1.4 steps in ground resolution means a difference this large was discriminated correctly about 67% of the time.

The implications of results of this experiment are that 1) the ground resolution of GEMS should be equally spaced logarithmically if they are to yield equal visible changes, and 2) if 67% accuracy of discrimination is desired, the change in the ground resolution of the GEMS should be about 1.4 log steps, where a step here was defined as a 10% decrease in ground resolution.

EXPERIMENT II

Purpose

The purposes of Experiment II were 1) to scale psychologically exposure shift and ground resolution; 2) to determine the change in exposure shift and ground resolution required for the subjects to discriminate reliably; 3) to determine the accuracy and reliability of judgment; and 4) to determine whether judgments of exposure shift and ground resolution are independent.

Method

GEMS. GEMS of three scenes were used in this study, Scenes A and B (those described in Experiment I), and an additional Scene C, an industrial site. Reference back to Table 1 shows the exposure shift and ground resolution of the Scenes-A and B GEMS. These are denoted by the cells containing X. There were 20 GEMS of Scene A, 20 GEMS of Scene B, and 70 GEMS of Scene C, one for each combination of exposure shift and ground resolution shown in Table 1.

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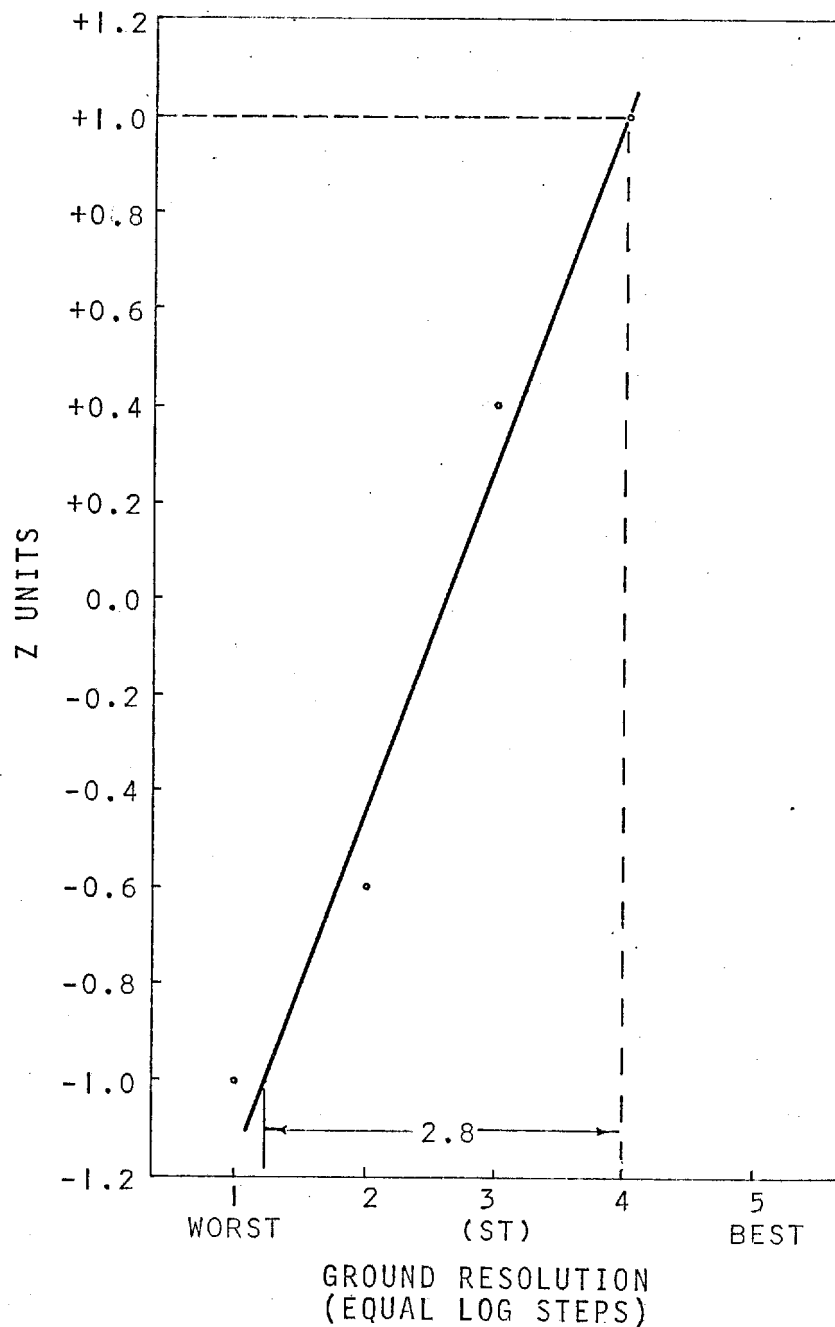


Fig. 2. The relation between ground resolution and judgments in Z units. All three series from Figure 1 combined.

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Experimental design. Table 2 (Page 10) shows the experimental design. Each subject made two judgments of Scene-A and Scene-B GEMS in relation to Scene-C GEMS. Five subjects judged the Scene-A GEMS first and the Scene-B GEMS second on Trial 1, and then judged the scenes in reverse order on Trial 2. The other six subjects judged the Scene-B GEMS first and the Scene-A GEMS second on Trial 1, and then judged the scenes in reverse order on Trial 2.

The order in which each subject judged the GEMS within a scene was randomized separately for each subject. The time between the judgments of Scene-A and B GEMS was not controlled--the subjects worked at their own pace. The minimum time between trials was about one day.

Subjects and procedure. The 11 subjects who participated in this experiment were experienced at viewing aerial photographs. Six of the 11 subjects had participated in Experiment I. The range of experience was one to 11 years with a median of five years.

The 70 Scene-C GEMS were numbered and arranged on a large light table in the form of a matrix as depicted in Table 1. Each of the Scene-A and Scene-B GEMS was assigned a random number.

Each subject was given a response sheet on which the numbers of Scene-A and Scene-B GEMS appeared. Opposite each number was a space provided for the number of the Scene-C GEM which the subject felt best matched the Scene-A (or B) GEM in both exposure shift and ground resolution. In other words, the subject's task was to match the exposure shift and ground resolution of each Scene-A and Scene-B GEM with that of a Scene-C GEM.

The subject's task was as follows: He took the Scene-A (or B) GEM, indicated on the response sheet, located its exposure-shift value by matching it to one of the rows of the matrix of Scene-C GEMS laid out on the light table next to him. He then located the resolution of a Scene-C GEM that best matched that of the Scene-A (or B) GEM he was judging. Next, he placed the Scene-C GEM on one stage of a B&L High-Power Stereo-Viewer and the Scene-A (or B) GEM on the other stage of the microscope. The final judgment of which Scene-C GEM best matched the A (or B) GEM in exposure shift and ground resolution was made on the microscope. Of course, the use of a stereo microscope required that the subject alternate between eyes in making this judgment.

Results and Discussion

Scaling. The first analyses of the data from this experiment were done to psychologically scale exposure shift

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TABLE 2
EXPERIMENTAL DESIGN

TRIAL	1		2	
	I	2	3	4
5 SUBJECTS	A	B	B	A
6 SUBJECTS	B	A	A	B

Note: A&B Denote Scenes.

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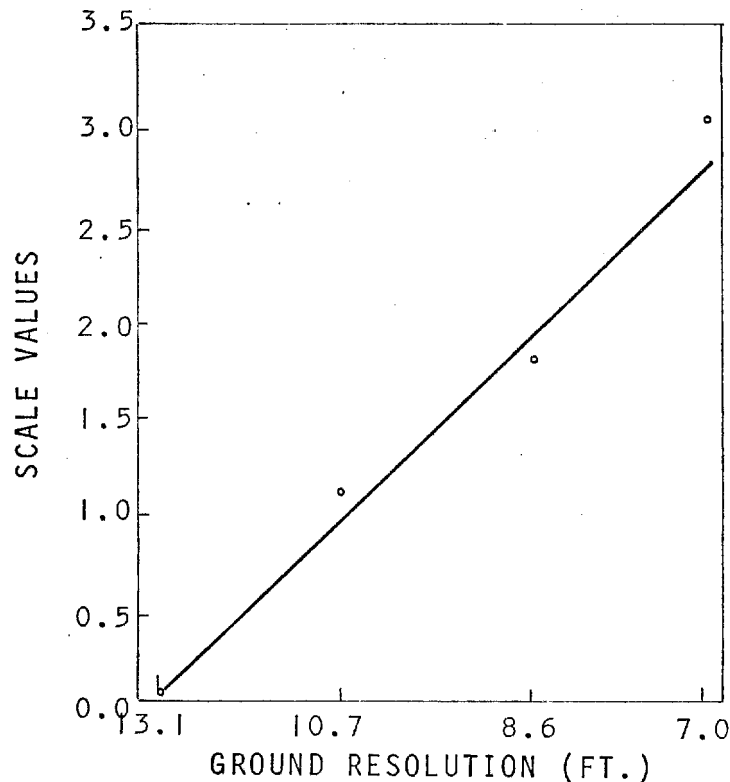


Fig. 3. The relation between ground-resolution and visual scale values.

and ground resolution. The scaling of ground resolution was accomplished by pooling the subjects' judgments of ground resolution over trials, scenes and exposure, and similarly, the scaling of exposure shift was accomplished by pooling their judgments of exposure shift over trials, scenes and ground resolutions.

The data were analyzed by a pair-comparison treatment of categorical data.²

Figures 3 and 4 (Page 12) show the results of the scaling for ground resolution and exposure shift. Figure 3 shows a linear relation between scale values and a log spacing of ground resolution (note that the ground resolutions are spaced at equal log intervals). Similarly Figure 4 shows a linear relation between scale values and exposure shift in density units.³ (Note also that density units are, in fact, on a log scale, so that the spacing on the abscissa in Figure 4 is also a log spacing.)

²For a description of this technique, see Guilford, J. P., *Psychometric Methods*. (2nd ed.) New York: McGraw-Hill, 1964. P. 242.

³A scale value for a density value of .23 was not computed because the proportions for that value were close to 1.00. Scale values should not be derived from proportions close to .00 or 1.00.

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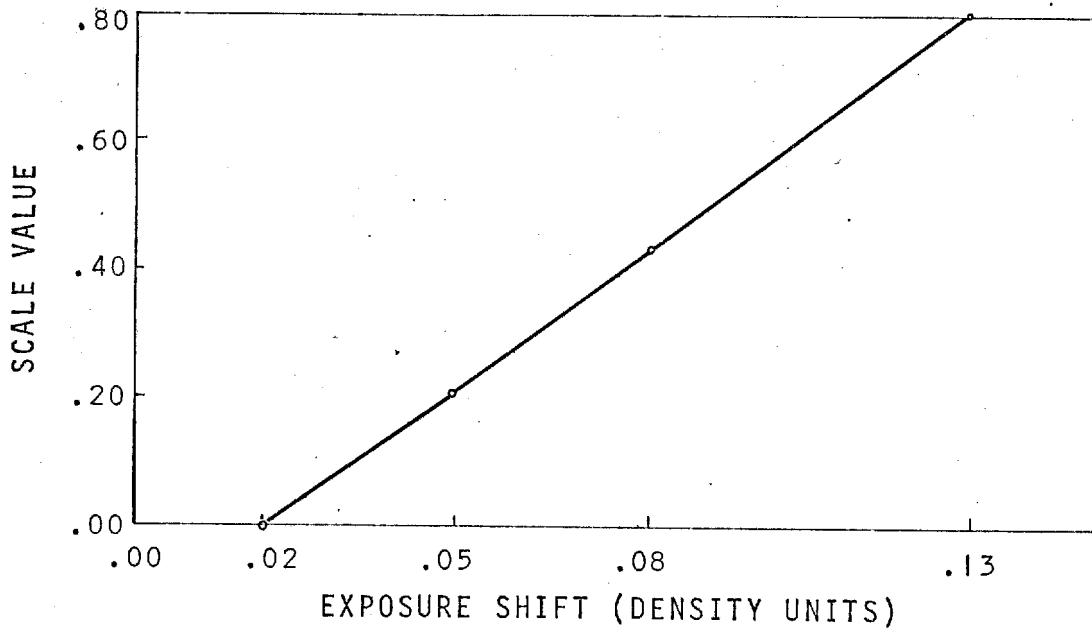


Fig. 4. The relation between exposure-shift and visual scale values.

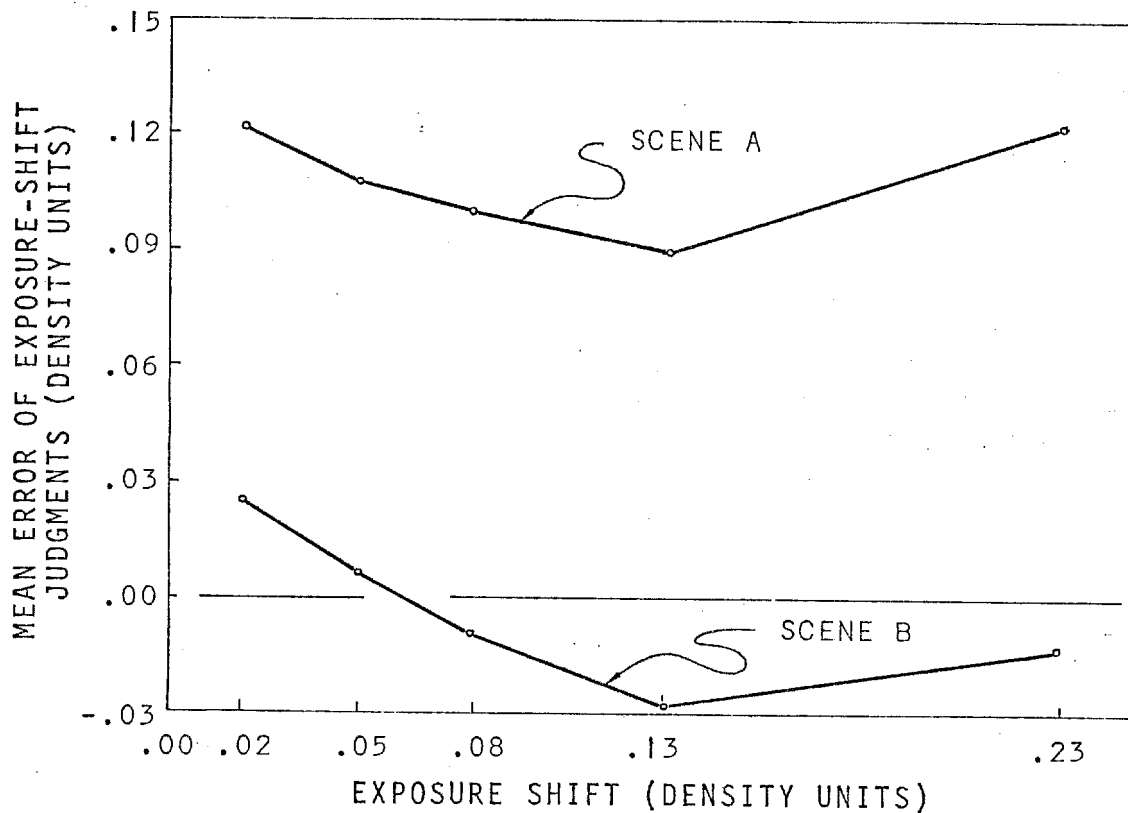


Fig. 5. Mean error of exposure-shift judgment as a function of exposure-shift and scene. (88 judgments for each data point.)

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The implications of these findings are that the increment in ground resolution of a GEM set should be set at equal logarithmic values and that the increment of exposure-shift values should be set at equal density values.

Accuracy of judgment. An exposure-shift and ground-resolution error was computed for each of the Scene-A and Scene-B GEMS for each subject. The exposure-shift error score was the density value of the Scene-C GEMS judged equal to the Scene-A (or B) GEM, minus the density value of the Scene-A (or B) GEM. Therefore, a positive error means the Scene-A (or B) GEM was judged to be more dense (overexposed), and a negative error means it was judged to be less dense (underexposed) than the Scene-C GEM. The ground-resolution error score was obtained by first assigning the numbers 1-10 to the worst (16.2 feet) through the best (6.3 feet) ground resolution of the Scene-C GEMS. The numbers 8, 6, 4, and 2 were assigned to the worst (13.1 feet) through the best (7.0 feet) ground resolutions of the Scene-A and Scene-B GEMS. The ground-resolution error score was the number of the Scene-C GEM judged equal in ground resolution to the Scene-A (or B) GEM, minus the number of the Scene-A (or B) GEM. Therefore, a positive error means that the Scene-A (or B) GEM was judged to have better ground resolution than the Scene-C GEM, and a negative error means it was judged to have worse ground resolution than the Scene-C GEM.

Table 3 (Page 14) shows the results of the analysis of variance of the errors of exposure-shift judgments. The analysis showed there were statistically significant differences among the mean errors for the different exposure-shift values ($F = 8.63$, $p < .001$), between the mean errors for scenes ($F = 68.13$, $p < .001$), and a statistically significant interaction between exposure shift and scenes ($F = 3.11$, $p < .05$). In addition, the analysis of variance showed a statistically significant difference between the mean errors on Trial 1 and 2 ($F = 5.83$, $p < .05$). The mean errors for Trials 1 and 2 were .059 and .046 density units. Although this decrease in error from Trial 1 to Trial 2 was statistically significant, it was small and of no practical significance.

Figure 5 (Page 13) shows the results associated with all the statistically significant effects, except for that of trials. The results showed that the errors in judging exposure shifts were much larger for Scene A than for Scene B. The mean error for Scene A was .108 density units, and that for Scene B was .003 density units. On the average then, the Scene-A GEMS were judged as denser than the Scene-C GEMS, and the Scene-B GEMS were judged as the same density as the Scene-C GEMS.

The change in mean error as a function of exposure shift (the bowing of the two curves) is a commonly observed

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TABLE 3
ANALYSIS OF VARIANCE OF ERRORS
OF EXPOSURE-SHIFT JUDGMENTS

SOURCE	df	MS	F
EXPOSURE SHIFT (A)	4	443.75	8.63***
GROUND RESOLUTION (B)	3	33.00	1.23
SCENE (C)	1	27,417.50	68.13***
TRIALS (D)	1	361.50	5.83*
SUBJECTS (S)	10	449.65	
A X B	12	33.67	1.17
A X C	4	109.12	3.11*
A X D	4	29.00	1.22
B X C	3	6.00	0.30
B X D	3	6.00	0.28
C X D	1	106.50	2.05
A X B X C	12	26.29	1.05
A X B X D	12	30.79	1.36
A X C X D	4	42.50	2.54
B X C X D	3	10.83	0.44
A X B X C X D	12	33.21	1.33
A X S	40	51.39	
B X S	30	26.75	
C X S	10	402.40	
D X S	10	62.00	
A X B X S	120	28.78	
A X C X S	40	35.09	
A X D X S	40	23.82	
B X C X S	30	20.10	
B X D X S	30	21.28	
C X D X S	10	51.85	
A X B X C X S	120	25.01	
A X B X D X S	120	22.71	
A X C X D X S	40	16.72	
B X C X D X S	30	24.52	
A X B X C X D X S	120	24.92	

***p < .001

*p < .05

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phenomena, often referred to as the "central tendency" effect.⁴ An explanation of this effect is beyond the scope of this study, but it should be pointed out that one explanation offered is that this effect is a result of imperfect discrimination. That is, averages of judgments of stimuli in a series often show some regression toward the central value of that series because of imperfect discrimination. This effect, when plotted as error in judgment, would look something like the curves shown in Figure 5.

The statistically significant exposure by scene interaction merely indicated that the difference between the mean errors for Scene A and Scene B at exposure value .23 was larger than the differences at the lower density values. This interaction probably reflects slightly different central tendency effects and is probably due to the fact that the density of the Scene-A GEM was considerably greater than that of the Scene-B GEMS (about .11 units). This means that the density of Scene-A GEMS ranged from about .13 to .34 on the density scale of the Scene-C GEMS. In effect then, the Scene-A GEMS were compared mainly against three standards from Scene C. That is, a standard of .13, .23, and one of .38 density units. Because the differences among the standards were so large, it is not surprising that the central tendency effect for Scene A was slightly different from that of Scene B.

Obviously, if imperfect discrimination produces a central tendency effect, one of the ways to reduce it is to make discriminations among the stimuli much easier. In the present case, this would mean that the increments should be considerably larger than the first few increments shown in Figure 5. The important point is that this regression or central tendency effect is not related to the accuracy with which the exposure-shift values were generated; the effect is strictly psychological and may be reduced by increasing the increment in exposure-shift values.

One of the purposes of this study was to determine if differences in ground resolution affected judgments of exposure shift, and whether differences in exposure shift affected judgments of ground resolution. Put in another way, are the judgments of exposure shift and ground resolution independent? If exposure-shift judgments are affected by the level of ground resolution, there should be a change in the mean error of exposure-shift judgments as a function

⁴Guilford, J. P., *Psychometric Methods*. (2nd ed.) New York: McGraw-Hill, 1954.

Helson, H., *Adaptation-Level Theory--An Experimental Approach to Behavior*. New York: Harper & Row, 1964.

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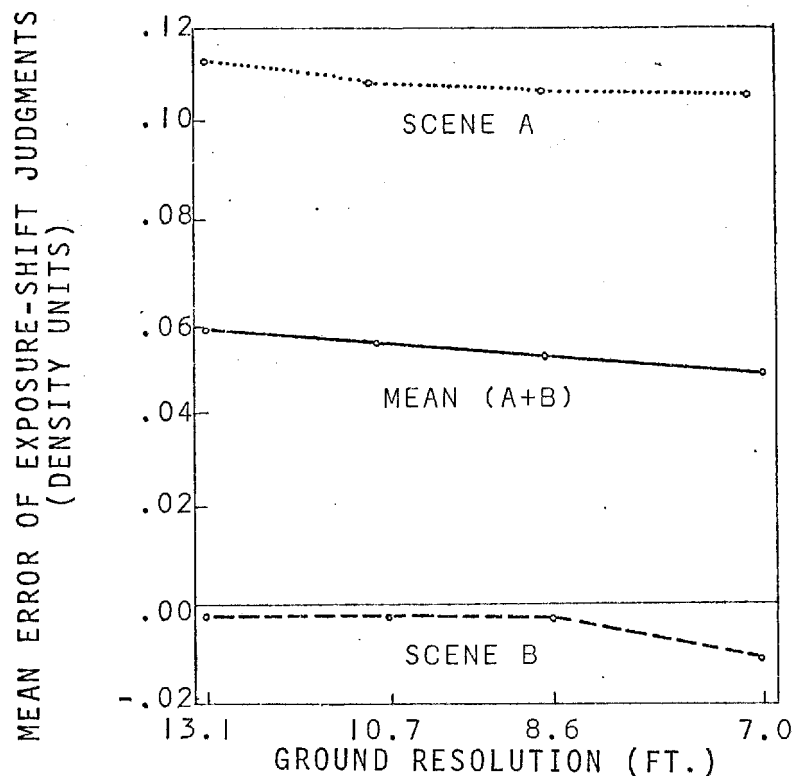
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Fig. 6. Mean error of exposure-shift judgments as a function of ground resolution and scenes. (110 judgments for each data point.)

of ground resolution, or as a function of a particular combination of ground resolution and exposure shift (resolution by exposure interaction). The analysis of variance showed that neither the effects of ground resolution, nor the ground resolution by exposure-shift interaction were statistically significant.

Figure 6 shows the mean error of exposure-shift judgments as a function of ground resolutions and scenes. The slight tendency for the mean error to decrease as ground resolution increased did not approach statistical significance ($F = 1.23$).

Table 4 (Page 17) shows the analysis variance of the errors of ground resolution judgments. Figure 7 (Page 19) shows the mean error of ground resolution judgments as a function of resolution and scenes.

Before proceeding with an interpretation of results shown in Figure 7, a few words of explanation may be necessary. A unit of 1.0 on the ordinate represents one log step in ground resolution as indicated in Table 1. Each ground-resolution value in the table represents one log step. So, if the Scene-A (or B) GEM was judged to

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TABLE 4

ANALYSIS OF VARIANCE OF ERRORS
OF GROUND-RESOLUTION JUDGMENTS

SOURCE	df	MS	F
EXPOSURE SHIFT (A)	4	3.75	2.97*
GROUND RESOLUTION (B)	3	14.67	3.21*
SCENE (C)	1	92.50	6.65*
TRIALS (D)	1	8.00	1.36
SUBJECTS (S)	10	13.70	
A X B	12	1.21	1.26
A X C	4	3.38	3.38*
A X D	4	0.50	0.70
B X C	3	8.00	4.70**
B X D	3	1.00	1.03
C X D	1	1.00	0.80
A X B X C	12	1.29	1.11
A X B X D	12	1.29	1.42
A X C X D	4	0.88	0.66
B X C X D	3	3.00	2.90
A X B X C X D	12	0.83	0.81
A X S	40	1.26	
B X S	30	4.57	
C X S	10	13.90	
D X S	10	5.90	
A X B X S	120	0.96	
A X C X S	40	1.00	
A X D X S	40	0.71	
B X C X S	30	1.70	
B X D X S	30	0.97	
C X D X S	10	1.25	
A X B X C X S	120	1.16	
A X B X D X S	120	0.91	
A X C X D X S	40	1.32	
B X C X D X S	30	1.03	
A X B X C X D X S	120	1.03	

* $p < .05$ ** $p < .01$ **SECRET**

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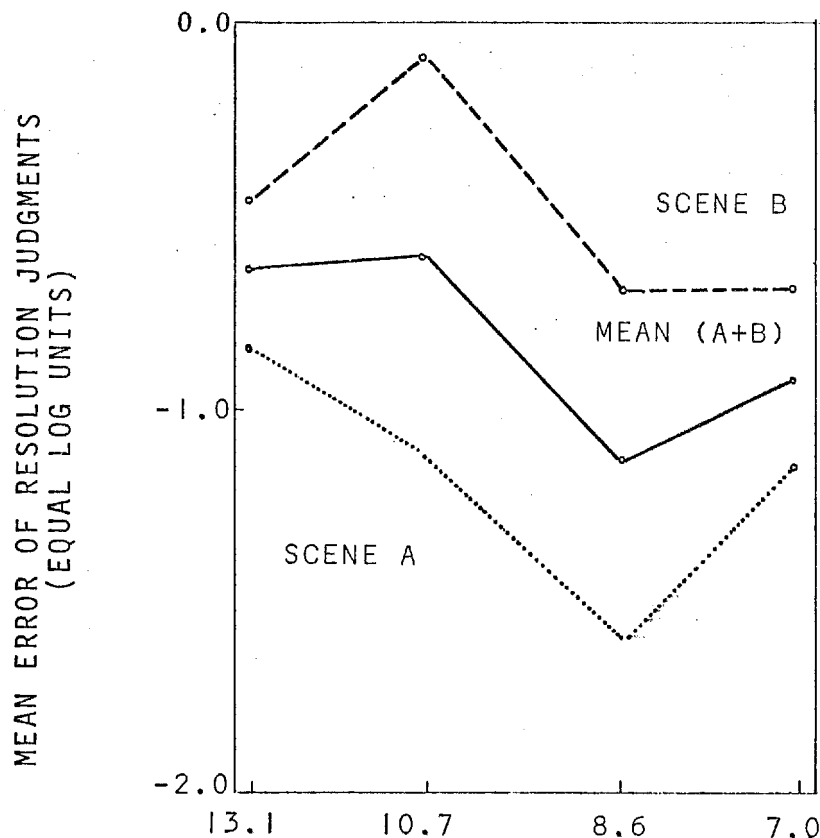


Fig. 7. Mean error of ground-resolution judgments as a function of resolution and scenes. (110 judgments for each data point.)

be -1.0 units, this means that it was judged to be one step worse in ground resolution than the Scene-C GEM. For example, a value of -1.0 for the Scene-A GEM at 10.7-feet ground resolution means that the Scene-A GEM that supposedly had a ground resolution of 10.7 feet was judged to be a little over one step worse than the Scene-C GEM. In other words, the Scene-A GEM was judged as equal to the Scene-C GEM that had a ground resolution of 11.8 feet.

Reference to the analysis of variance table and inspection of Figure 7 showed that there was an overall tendency (mean of curves A and B) for the mean error to increase as the ground resolution improved. This effect was statistically significant ($F = 3.21$, $p < .05$). In addition, the interaction between ground resolution and scene was statistically significant ($F = 4.70$, $p < .001$). This interaction indicates that the difference in mean error between the two scenes was greater at 10.7 and 8.6 feet than it was at 13.1 and 7.0 feet.

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The most obvious effect in Figure 7 is that the ground resolution of both the Scene-A and Scene-B GEMS was judged to be worse than that of the Scene-C GEMS. In addition, the ground resolution of the Scene-A GEMS (mean = -1.2) was judged to be worse than that of the Scene-B GEMS (mean = -0.5). The difference between mean errors for the two scenes was statistically significant at the .05 level ($F = 6.65$). This result is consistent with that cited in Experiment I. In Experiment I, the Scene-B GEMS were compared directly with Scene-A GEMS, in contrast with the present experiment in which the Scene-A and B GEMS were compared with the Scene-C GEMS. Despite the difference in techniques, both experiments indicate that the ground resolution of Scene-A GEMS was worse than that of Scene-B GEMS.

The slight increase in the error as ground resolution improved is probably due to the central tendency effect discussed in Experiment I. In addition, the significant interaction between scene and resolution was probably a result of a differential central tendency effect. As was pointed out in Experiment I, variations in the mean error of judgment as a function of the stimulus position in a series is a common finding in psychophysics.

In conclusion, the differences among the judged ground resolutions of the GEMS of the three scenes probably reflect a true difference among ground resolutions, and are not due to the judgmental process. The other effects shown in Figure 7, the change of error as a function of ground resolution and the interaction between scenes and ground resolution, are probably a result of the judgmental process.

Figure 8 (Page 20) shows the mean error of ground resolution judgments as a function of exposure shift and scenes. The analysis of variance showed that the effects of exposure shift ($F = 2.97$, $p < .05$), and exposure shift by scenes ($F = 4.70$, $p < .001$) were statistically significant. The exposure-shift effect is shown as the mean of the errors for Scenes A and B combined. Additional statistical analysis showed that the mean error was larger for the .23-density GEMS than it was for the GEMS having a lower density value ($q_r = 4.59$, $p < .05$)⁵. The statistically significant interaction between exposure shift and scenes indicates that the difference between mean errors for Scene A and B at .23 density was larger than the

⁵The q_r statistic is test of the difference between individual pairs of means, and is used after an overall significant difference among means has been obtained. Winer, B. J., *Statistical Principles In Experimental Design*. New York: McGraw-Hill, 1962. P. 77.

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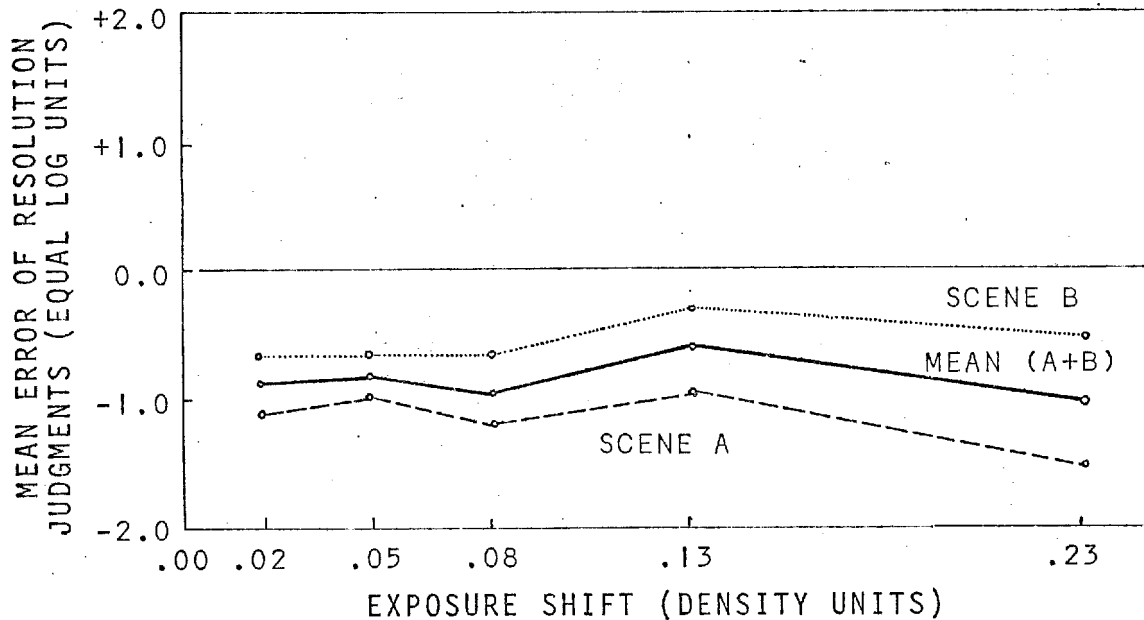


Fig. 8. Mean error of ground-resolution judgments as a function of exposure shift and scenes. (88 judgments for each data point.)

differences at the lower density levels. The statistically significant effect of exposure shift and the significant interaction were due to the larger error for the Scene-A .23-density GEMS. That is, there was no consistent change in the mean error of ground resolution judgment as a function of exposure shift.

One possible explanation of the results shown in Figure 8 is as follows: It will be recalled that the Scene-A GEMS were judged to be considerably more dense than the Scene-C GEMS (by about .11 density units). This means that the range of density for the Scene-A GEMS was somewhere between .13 and .34. It is possible, then, that dense photographs will be judged to have a slightly worse ground resolution than less dense ones.

Generally speaking, the results in Figure 8 showed no consistent trends in changes of errors of ground resolution judgments as a function of exposure shift. In addition, the analysis of variance showed that there was no significant interaction between exposure shift and ground resolution. These two results taken together seem to indicate that ground resolution judgments are independent of the exposure shift (density) of the photograph. A possible exception is when the photograph is extremely dense.

Reliability of judgment. In addition to estimating the mean error, two estimates of reliability were obtained for the exposure-shift judgments, and two for the ground-

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resolution judgments. One estimate of reliability was the typical standard deviation of the subjects' errors of judgment for one GEM. To obtain an estimate of the typical standard deviation, a standard deviation of the errors of exposure-shift judgments was computed for each of the 20 GEMS of each scene for each of the two trials. The same was done for the errors of ground-resolution judgments.

Table 5 (Page 22) shows these means of the standard deviations. Note that the differences between the mean standard deviations for the two scenes were very small; consequently a mean standard deviation for the two scenes was computed for both exposure-shift and ground-resolution judgments. Interpretation of the standard deviation is as follows: Given a single photograph, one would expect about two-thirds of the subjects to judge the exposure shift of that photograph to be within $\pm .06$ density units of the true value. The standard deviation of the ground resolution judgments should be interpreted in the same way.

Another index of reliability is the variability of the mean of the subjects' judgments. The expected standard deviation of the mean error of exposure-shift judgments (often referred to as the standard error of the mean) was about .02 density units. The standard error of the mean for the ground-resolution judgments was about .4 log units. The standard error of the mean is interpreted in much the same way as a standard deviation, the difference being that the standard error of the mean refers to the variability of the mean and not the individual judgments. For example, the standard error of .02 density units is interpreted as follows: If new groups of subjects were drawn randomly from the same population, two-thirds of their mean exposure-shift judgments for one GEM should lie within $\pm .02$ density units of the true value.

The interpretation of both indices of reliability discussed above is based on the assumption that the mean of the subjects' judgments is, in fact, the best estimate of the true value of the GEM.

It is suggested that the spacing between adjacent GEMS in a GEM set should be at least one standard deviation apart. A separation of one standard deviation or more should make discrimination among GEMS considerably easier than in this study. As a result, there should be less variation in the errors in judgment due to the nonlinearity of the judgment process (the central tendency effect).

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TABLE 5
MEANS OF THE
STANDARD DEVIATIONS

	EXPOSURE SHIFT (DENSITY)	GROUND RESOLUTION (LOG UNITS*)
SCENE A	.065	1.22
SCENE B	.056	1.28
MEAN A & B	.060	1.25

*1 Log unit equals 1 step as shown
in TABLE 1.

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EXPERIMENT III

Purpose

The purpose of Experiment III was to determine the reliability of exposure-shift and ground-resolution judgments of mission photographs. Put in another way, the purpose was to determine how well different subjects agree on the exposure shift and ground resolution of mission photographs.

Method

Photographs. The 70 Scene- C GEMS described in Experiment II were used as standards against which mission photographs were matched. Sixteen mission photographs (original negative transparencies) were selected for judgment. These photographs were from different missions and differed in scene content.

Subjects and procedure. Eleven experienced subjects participated in this experiment. Ten of these subjects had participated in Experiment II. The task of the subjects was essentially the same as that in Experiment II, except mission photographs, instead of GEMS, were matched to GEMS. The only differences in procedure were 1) the general area of the mission photograph to be judged was marked with a cross on the Polaroid print of the mission photograph, and 2) the GEM was viewed at 20X magnification, and the mission at 60X magnification. This latter change in procedure was necessary because GEMS were fabricated at three times the scale typical of mission photographs, and at one-third the ground resolution in lines per millimeter. Therefore, viewing the mission photographs at three times the magnification of the GEMS equated the ground resolution at the eye.

The order of judging the photographs and the rest periods were left to the discretion of each subject.

Results and Discussion

One of the subjects did not judge exposure shift when he judged the mission photograph to be worse in resolution than the GEM. Consequently, the means and standard deviations of exposure-shift judgments, shown in Table 6 (Page 24), are based upon the judgments of 10 subjects.

Table 6 shows the mean and standard deviation of the mission-photograph judgments. A mean and standard deviation was not computed for all of the photographs.

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TABLE 6
MEANS AND STANDARD DEVIATIONS
OF MISSION AND PHOTOGRAPH JUDGMENTS

		GROUND RESOLUTION (FEET)			EXPOSURE SHIFT (DENSITY UNITS)		
		MEAN	-1 σ	+1 σ	MEAN	-1 σ	+1 σ
MISSION PHOTOGRAPH NO.	1	-	-	-	.072	.033	.121
	2	-	-	-	-	-	-
	3	-	-	-	.205	.126	.284
	4	12.9	10.7	14.9	.174	.097	.251
	5	-	-	-	.255	.137	.373
	6	-	-	-	-	-	-
	7	14.8	13.6	16.0	-	-	-
	8	-	-	-	.044	-.004*	.092
	9	13.0	10.1	16.7	.172	.071	.273
	10	13.0	10.5	16.0	.096	.056	.136
	11	-	-	-	.098	.021	.175
	12	12.6	9.6	16.6*	.065	.049	.081
	13	-	-	-	.030	-.003*	.063
	14	-	-	-	.180	.127	.233
	15	11.2	9.1	13.8	.041	.010	.072
	16	11.2	9.3	13.5	.045	.020	.070

*Extrapolated

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Several photographs were judged to be beyond the range of the density of the GEMS, or worse in ground resolution than the GEMS. If two or more subjects were unable to match the mission photograph to a GEM, a mean and standard deviation was not computed for that mission photograph.

The ground resolution values were obtained as follows: The ground resolution of the GEM matched to the mission photograph was converted into log ground resolution for each subject. A mean and standard deviation of the log values were computed, and the antilog of these values was taken, thereby giving ground resolution in feet. The exposure-shift mean and standard deviation for each mission photograph were computed from the density values of the GEMS judged to be equal to the mission photograph.

The mean of the standard deviations for ground resolution was 1.9 log units (where one unit equals one step, as shown in Table 1). This value is slightly larger than the standard deviation of 1.25 for matching one GEM of one scene to the GEM of another scene. A statistical test showed that the difference between the two standard deviations was not statistically significant ($t = 2.09$, $p < .10$).

The mean of the standard deviation for exposure shift for the mission photographs was about the same as it was when the GEMS of one scene were matched with the GEMS of another scene. The mean standard deviation for the mission photographs was .065 density units, while that for the GEMS was .060 density units.

It is concluded that the agreement among subjects on the ground resolution and exposure shift of the mission photographs was about as good as that on the GEMS.

The exact ground-resolution or exposure-shift values of the mission photographs were not known. Consequently, there is no way of knowing whether the means cited in Table 6 are accurate, but it does seem that the ground resolution means are slightly larger than what would be expected from a random sampling of mission photographs from the photographic system considered here.

IMPLICATIONS

Results of Experiment I and II were interpreted as indicating that the average ground resolution of the GEMS of the three scenes differed. In addition, the Scene-A GEMS were judged to be more dense than the Scene-C GEMS.

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There is no direct way of knowing from the data whether the differences cited above are a result of human judgment or physical differences among the GEMS, but the results strongly suggest physical differences. A re-assessment of the ground resolution and density of the original negatives from which the GEMS were made, as well as a retracing of the fabrication of the GEMS should clarify the cause of the differences. If those differences are not attributable to physical differences in the GEM sets, and consequently, a result of human judgment, this finding would severely limit the usefulness of GEMS as standards against which to compare mission photographs.

A very encouraging finding of the present study was that scene content had little or no effect on how well the subjects agreed on either the ground resolution or the exposure shift of the scene. This finding, though not conclusive since only three scenes were used, strongly suggests that one, or possibly a few scenes, may be sufficient for a GEM set.

The agreement among subjects (standard deviation) on the ground resolution and exposure shift reported in this study may be slightly better under optimal viewing conditions. The subjects in this study were required to compare two photographs by viewing them alternately with one eye and then the other. Obviously this required the subject to remember which of the two photographs had a better ground resolution and which of the two was more dense. Another deficiency of the present technique was that the characteristic of the two sets of optics of the microscope and those of the subjects' eyes may not have been equal. Even better agreement among subjects may have been obtained if a split-field microscope were available--a microscope with which the subject could view both photographs simultaneously.

The recommendations directly relevant for the production of a GEM set are summarized below. These recommendations are based on the assumption that the observed differences of ground-resolution and exposure-shift judgments among scenes were due to physical differences between the scenes.

1. There was a linear relation between exposure shift (in density) and visual scale values, and between the log of ground resolution and visual scale values. The implications of these findings are that a) the increment in exposure shift of the GEMS should be at equal density values, and b) the increment in ground resolution of the GEMS should be at equal log ground-resolution values.

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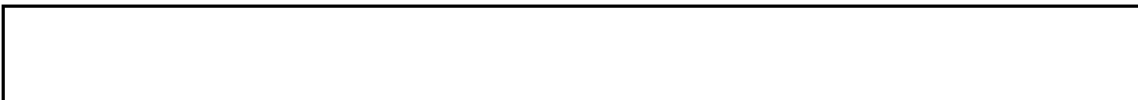
2. The increment should be at least .06 density units (one standard deviation) for exposure shift and 1.3 log units (one standard deviation) in ground resolution, where one log unit equals a 10% decrease in ground resolution.

One advantage of increasing the differences between GEMS to about one and one-half the standard deviation, would be to reduce the nonlinearity of the judgment process (central tendency effect). This nonlinearity is due partly to the difficulty of discriminating among the stimuli in the series. If the differences among the stimuli are made sufficiently large, one would expect a reduction in the nonlinearity of the judgment process. On the other hand, the differences between GEMS should be small enough to be useful for engineering evaluations of system performance.

3. Generally speaking, the results showed that the level of exposure shift did not affect the judgments of ground resolution, with the exception of possibly the exposure shift of about .34 density units, and that ground resolution did not affect the judgments of exposure shift. These results imply that a GEMS matrix is not required for these two photographic dimensions; that is, a GEM is not required for each combination of exposure shift and ground resolution. All that is required is one series of GEMS representing differences in ground resolution and one series of GEMS representing differences in exposure shift.

Whether or not a set of GEMS would be useful depends on the speed as well as the accuracy of human judgment. This study was designed to answer only the question of accuracy. However, there is evidence that indicates human beings can make ground-resolution judgments rather rapidly. One investigator⁶ found that professional photo interpreters ranked the ground resolution of grainless pictures just as accurately within a 20-second time limit as they did when they had no time limit. Of course, those pictures were grainless, and a different result may be

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obtained with grainy photograph's. In any case, his results do suggest that humans can make ground-resolution judgments rather rapidly without seriously affecting the accuracy of judgment.

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APPENDIX B

Psychophysical GEMS Matrix Data Report

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The GEMS matrix array is composed of elements varying both in modulation transfer function (MTF) and exposure for three different scenes. The GEMS matrix was fabricated to simulate the appropriate mission material under specific viewing conditions; i.e. when the mission material and GEMS are viewed at 60 and 20 times magnification, respectively. The differences in grain size and scale factor, which would normally exist at these two viewing magnifications, were properly adjusted in the simulation process.

Matrix Element Identification

A matrix element was used to identify the particular elements within the matrix array. The first digit (or first two digits in a three-digit code number) indicates the level of MTF where the number (1) represents the highest and the number (10) represents the lowest. The second digit (or third digit in a three-digit code number) indicates the level of exposure where the number (1) represents the minimum exposure and the number (7) represents the maximum exposure.

Parameter Specifications

Data sheets defining the objective evaluation of the MTF and exposure parameters for the matrix are included as Figures 1 and 2 of this report. The MTF increments of the GEMS are representative of 10 percent changes in limiting scene ground resolution and depicted by 0.45 modulation response curves. The increment spacings for the seven exposure levels were varied from 0.02 to 0.15 density units to achieve a total exposure shift of 0.38 density units between exposure elements 1 and 7. Reference Figure 2 for the exact value of each increment shift.

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The ranges of the MTF and exposure parameters were determined to be most appropriate from the System Parameters Study and most representative of the desired ranges to be tested. Use of a 0.45 modulation response level in the evaluation of the simulated MTFs was considered a good compromise between being representative of mission material and providing a fair degree of precision in the MTF determination process.

The limiting scene ground resolutions reported in Figure 1 correlate with the GEMS directly. When the GEMS are compared with the mission material at the viewing magnifications given above, the limiting scene ground resolutions (in lines per millimeter) are increased by a factor of three. (See table below)

MTF Code Digit(s)	GEMS Scene Ground Resolution(1/mm)	Viewing Factor
		GEMS Scene Ground Resolution(1/mm)
1	58.7	176.1
2	52.8	158.4
3	47.5	142.5
4	42.8	128.4
5	38.5	115.5
6	34.7	104.1
7	31.2	93.6
8	28.1	84.3
9	25.3	75.9
10	22.8	68.4

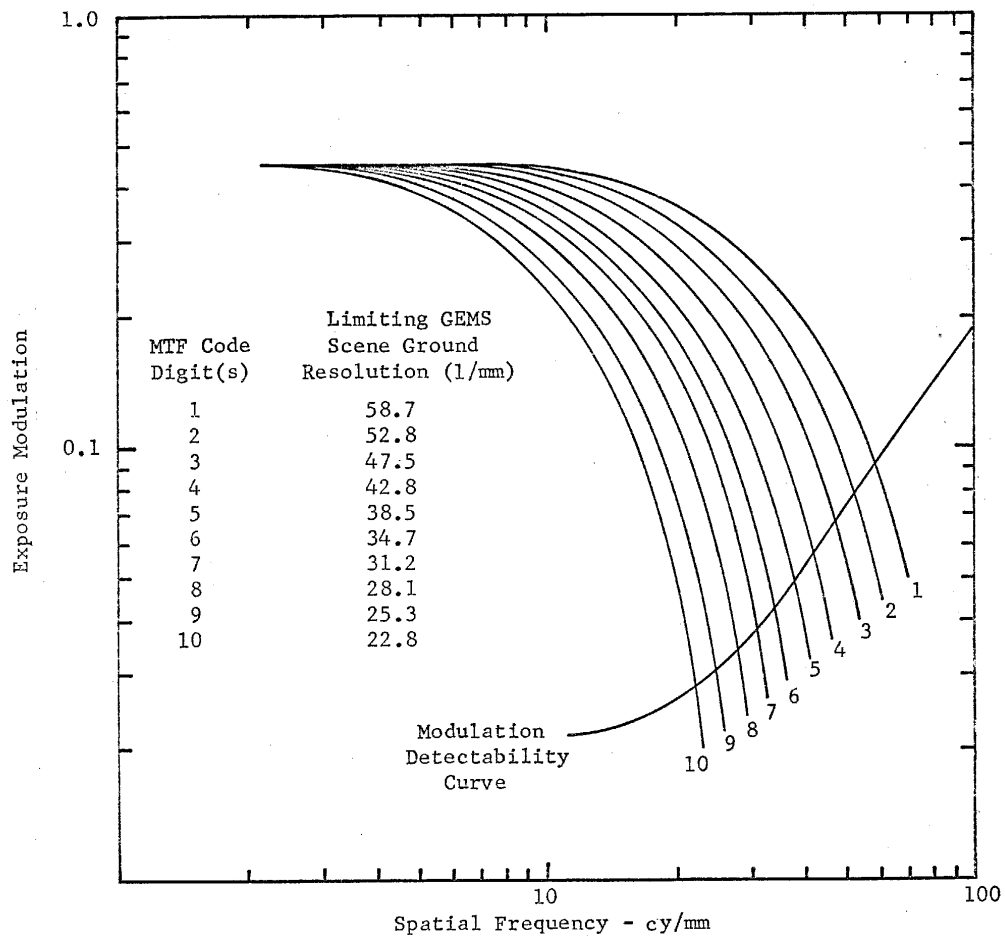


Figure 1. Modified MTF Curves for Matrix Array

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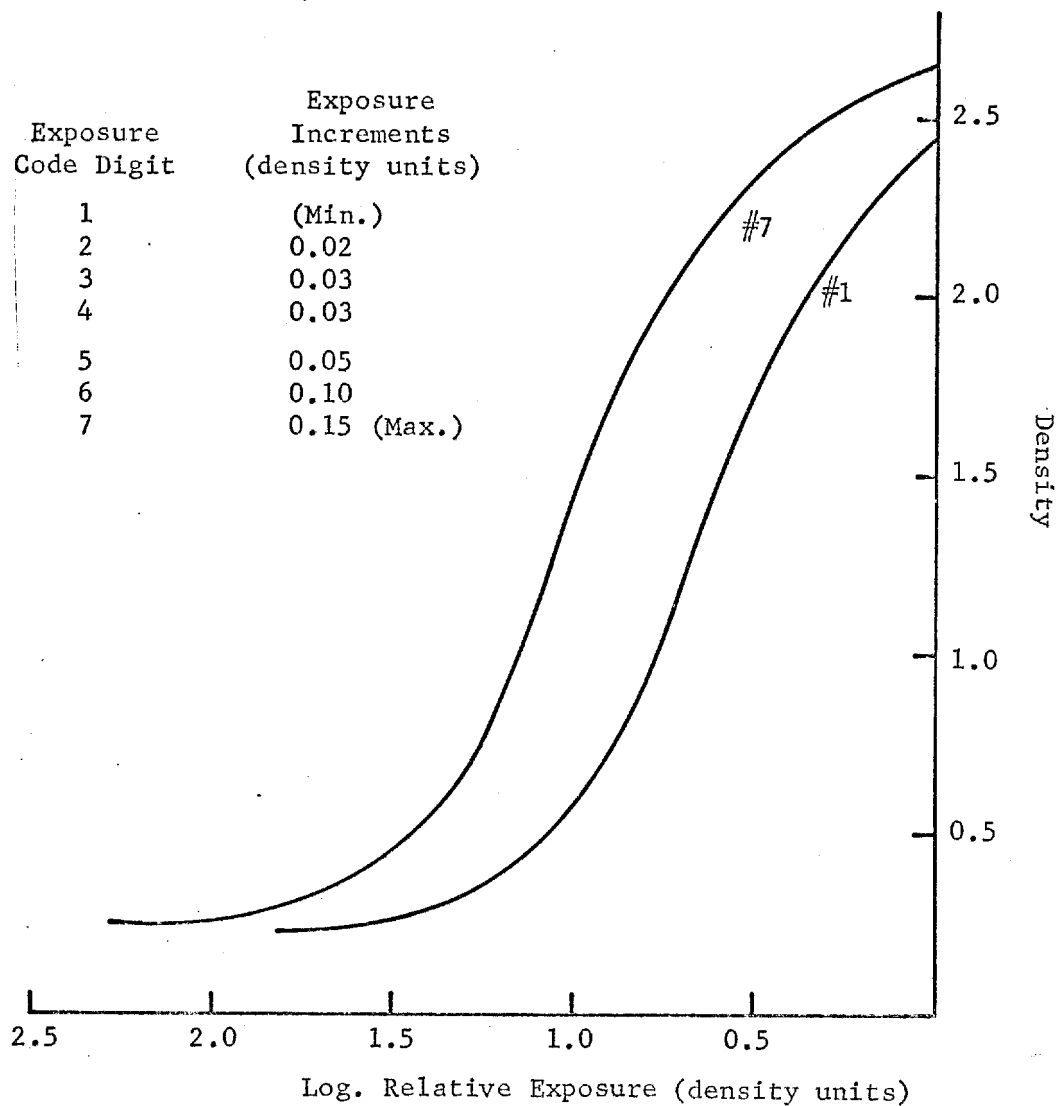


Figure 2. Exposure Increments for Matrix Array

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